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**A SIMPLIFIED METHOD FOR DETERMINING
THE PURITY AND LUMINOUS REFLECTANCE
OF 42-LB. UNBLEACHED KRAFT LINERBOARD**

Project 1108-15

Progress Report Three

to

FOURDRINIER KRAFT BOARD INSTITUTE, INC.

May 1, 1958

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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SUMMARY

In previous studies, a method for measuring the color characteristics of 42-lb. unbleached kraft liner was developed based on reflectance measurements at four wavelengths, namely, 457, 512, 582, and 596 m μ . Measurement of the color characteristics of a large number of samples by this method indicated that the dominant wavelength for all samples was essentially a constant near 582.0 m μ . If the assumption is made that the dominant wavelength is constant, the method described above based on reflectance measurements at four wavelengths may be simplified and the purity and luminous reflectance of such samples may be computed if reflectance measurements at only two wavelengths (457 and 596 m μ) are known.

To evaluate the merits of this simplification, purity and luminous reflectance values for 51 samples of kraft linerboard were computed from only two reflectance measurements. These were then compared with similar values computed from four reflectance measurements on the same samples.

The results indicated that the two methods yielded closely equivalent results. The simplified method based on two reflectance measurements may, therefore, be recommended for use in the measurement of the purity and luminous reflectance of 42-lb. unbleached kraft linerboard.

INTRODUCTION

During 1956 and 1957, The Institute of Paper Chemistry was engaged in a study of the color characteristics of 42-lb. kraft liner for the Fourdrinier Kraft Board Institute. The objectives of the study were as follows:

1. To develop methods of measuring the color characteristics of 42-lb. kraft liner.
2. To develop methods for specifying the color of 42-lb. kraft liner.

The results of the investigation were summarized in two reports to the co-operator (1, 2).

With regard to the first objective, examination of color curves for a number of kraft liner samples revealed that the color curves for 42-lb. unbleached kraft liner were of two types--i.e., a relatively straight line with a single slope or a curve which could be fitted with two intersecting straight lines. In the latter case, the point of intersection was near 540 m μ for all samples examined. In the case of a straight line, the spectral reflectances at two wavelengths within the visual range may be used to define the color curve. For the case of two intersecting straight lines, the color curve may be defined by spectral reflectances measured at four appropriate wavelengths.

Based on the above evidence, a method of color measurement was developed using the G. E. reflection meter with four special filters. The filter wavelengths were 457, 512, 582, and 596 m μ . From the reflectance measurements at these wavelengths, the dominant wavelength, purity and luminous reflectance could be computed.

When the above procedure was utilized to measure the color characteristics of a large number of 42-lb. kraft liner samples, it was found that the dominant wavelength was nearly constant for all samples at about 582 m μ . An overwhelming proportion of the samples exhibited dominant wavelengths in the 581 to 583 m μ . range. Extreme values of 580 and 584 m μ were recorded for only a few samples.

It was then noted that, if the dominant wavelength for all samples of linerboard could be considered a constant, a relationship between the tri-chromatic coefficients (x' and y) must result, i.e., $y = a + bx$ where a and b are constants. The existence of such a relationship implies that it should be possible to compute the purity and luminous reflectance of 42-lb. unbleached kraft liner from reflectance measurements at two wavelengths--namely, 457 and 596 m μ . The result, therefore, would be to reduce by one half the number of measurements required to define the color characteristics of kraft liner. For this reason, it appeared desirable to compare values of purity and luminous reflectance, computed by each of the two methods. The results of such a comparison are summarized herein.

MATERIALS

During the months September, 1956, through February, 1957, each sample of kraft linerboard submitted in connection with the "Continuous Baseline Study of Kraft Liner" was evaluated to determine its dominant wavelength, purity and luminous reflectance (2). The characteristics were computed by the method of two selected ordinates using reflectance measurements at 457, 512, 582, and 596 m μ . For the purpose of comparing the previous results with calculations

using only the reflectance measurements at 457 and 596 mμ, the data obtained during January, 1957, were re-analyzed. The first three samples submitted by each mill during January were selected.

PROCEDURE

A. METHOD OF SELECTED ORDINATES--FOUR REFLECTANCE MEASUREMENTS

This method was described in Progress Report 2 and is outlined below in stepwise fashion.

1. The reflectance of each specimen (five specimens are usually employed) is measured at each of the following wavelengths: 457, 512, 582, and 596 mμ.

2. The five readings at each of the above wavelengths are averaged together and substituted in the equations below to compute the tristimulus values X, Y, and Z.

$$X = \frac{0.9804 [10.60 R_{456} + 44.77 R_{596}]}{55.37} \quad (1)$$

$$Y = \frac{17.39 R_{512} + 38.35 R_{582}}{55.74} \quad (2)$$

$$Z = 1.1812 R_{455} \quad (3)$$

In these equations, R is the reflectance at the indicated wavelength. The measured value of the reflectance at 457 mμ is used in place of the reflectance at 455 or 456 mμ.

3. The tristimulus values (X, Y and Z) are then added together and each tristimulus value is divided by the sum to obtain the trichromatic coefficients x and y. Thus,

$$x = \frac{X}{X + Y + Z} \quad (4)$$

$$y = \frac{Y}{X + Y + Z} \quad (5)$$

4. The dominant wavelength and purity are then determined from the trichromatic coefficients (x and y) by reference to suitable chromaticity diagrams. A section of the chromaticity diagram (Chart No. 13) of use in this particular study is shown in Figure 1.

5. The luminous reflectance value is equal to the tristimulus value Y and is customarily rounded off to the nearest 0.1%.

An example of the measurements and calculations entailed in the above was summarized in Progress Report Two.

B. METHOD OF SELECTED ORDINATES--TWO REFLECTANCE MEASUREMENTS

From Figure 1 it may be noted that, at any dominant wavelength, there is a linear relationship between the trichromatic coefficients x and y, i.e., $y = a + bx$ where a and b are constants. If this relationship is substituted in the equation $x + y + z = 1$, it may be shown that

$$S = \frac{(1 + b)X + Z}{1 - a} \quad (6)$$

where $S = X + Y + Z$.

In Equation 1, X is a function of the reflectances at 457 and 596 mμ, while Z is a function of the reflectance at 457 mμ. Therefore, if reflectance measurements at 457 and 596 mμ are available, X and Z and finally S may be

Chart No. 13

75

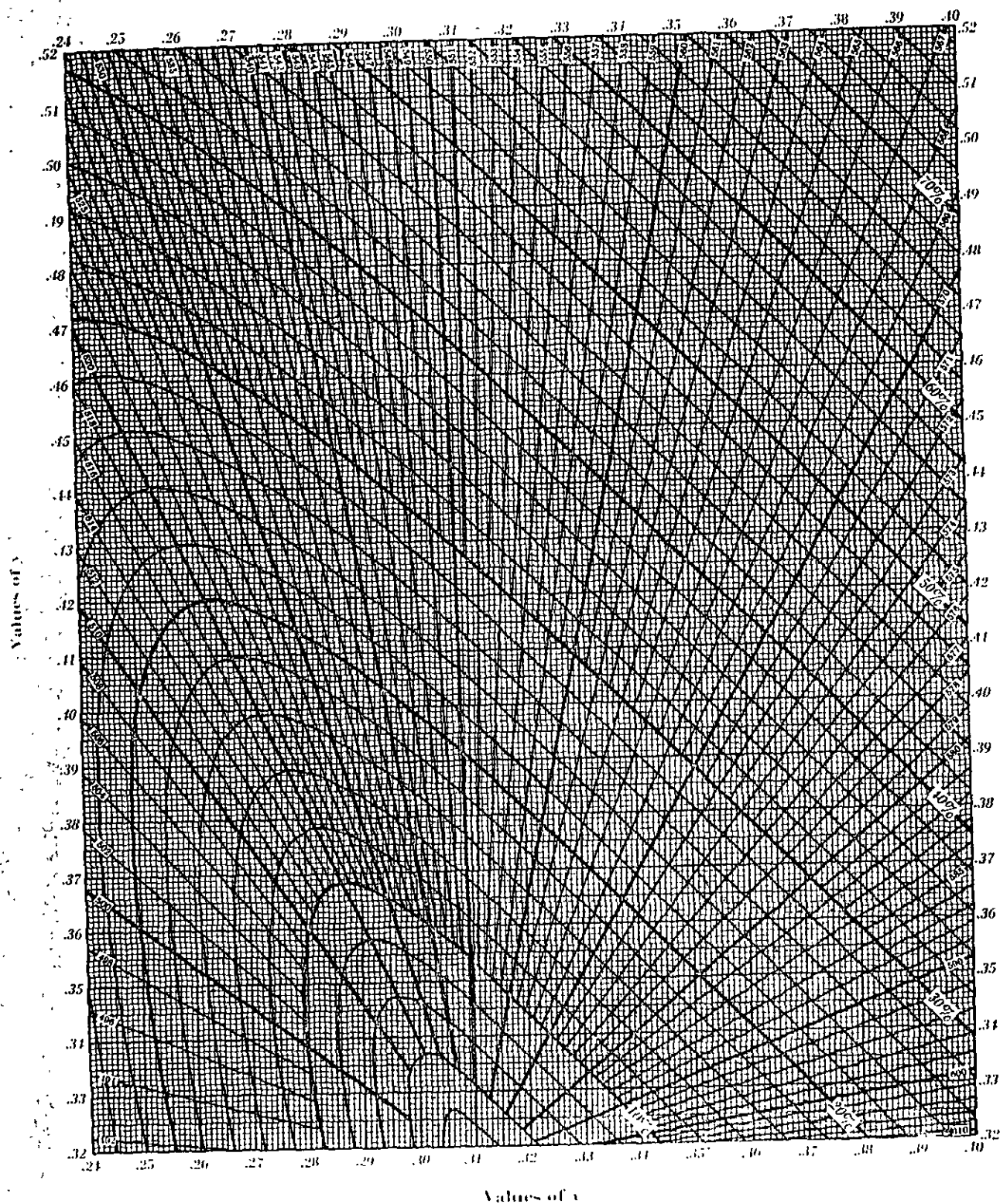


Figure 1. Chromaticity Diagram

computed. If S and X are known, the trichromatic coefficients x and y and the tristimulus value Y may also be computed. The purity may then be read from the chromaticity diagrams in the usual manner. The net result, therefore, is that the color characteristics are defined by two reflectance measurements rather than four.

To determine the constants in the equation relating the trichromatic coefficients x and y, values of x and y were read from chromaticity chart 13 (see Figure 1) at a dominant wavelength of 582 mμ. The values are shown below in Table I.

TABLE I
VALUES OF THE TRICHROMATIC COEFFICIENTS AT A
DOMINANT WAVELENGTH OF 582 MMU

y	x
0.3380	0.3400
0.3455	0.3500
0.3527	0.3600
0.3600	0.3700
0.3673	0.3800
0.3748	0.3900
0.3823	0.4000
0.3163*	0.3101*

* Co-ordinates of illuminant C (2).

A straight line was fitted to the above data by the method of least squares. The resulting values for the slope and intercept were 0.733,380 and 0.088,380, respectively, i.e.,

$$y = 0.088,753 + 0.733,380x \quad (7)$$

Using the above equations, the calculation procedures are outlined below in stepwise fashion.

1. Measure the reflectance of the sample at 457 and 596 mmu.
2. Substitute the average values at each wavelength in Equations 1 and 3 to compute X and Z.
3. Calculate S (equals $X + Y \times Z$) using Equation 6.
4. Divide the tristimulus value X by S to obtain the trichromatic coefficient x.
5. Substitute x in Equation 7 to compute the trichromatic coefficient y.
6. Multiply y by S to obtain the tristimulus value Y which is equal to the luminous reflectance.
7. Enter the chromaticity chart at the value of x and y and read the purity.

DISCUSSION OF RESULTS

As discussed previously, this report compares estimates of purity and luminous reflectance computed from (1) four reflectance measurements, and (2) two reflectance measurements. The results obtained are summarized in Table II where it may be noted that the methods yielded closely equivalent results. A frequency distribution of the differences is shown in Table III.

TABLE II
COMPARISON OF ESTIMATES OF PURITY AND LUMINOUS REFLECTANCE
COMPUTED FROM TWO AND FOUR REFLECTANCE MEASUREMENTS

Mill	File No.	Luminous Reflectance, %			Purity, %			Dominant Wavelength, ^a mmu
		Four Reflec- tance Method	Two Reflec- tance Method	Differ- ence	Four Reflec- tance Method	Two Reflec- tance Method	Differ- ence	
A	173059	23.78	23.98	+0.20	30.1	30.3	+0.2	583.0
	173060	22.38	22.42	+0.04	29.6	29.8	+0.1	582.0
	173171	25.24	25.46	+0.22	28.5	28.8	+0.3	582.5
B	173152	24.73	24.88	+0.15	28.4	28.5	+0.1	582.5
	173163	24.19	24.09	-0.10	29.1	29.1	0.0	581.5
	173249	24.86	25.05	+0.19	28.0	28.3	+0.3	582.5
D	173125	22.19	22.41	+0.22	28.2	28.5	+0.3	583.0
	173126	22.37	22.42	+0.05	27.9	28.0	+0.1	582.0
	173142	21.82	21.93	+0.11	29.1	29.1	0.0	582.5
E	173188	23.64	23.74	+0.10	27.7	28.0	+0.3	582.5
	173189	24.76	25.02	+0.26	28.2	28.6	+0.4	583.0
	173302	24.18	24.28	+0.10	27.5	27.5	0.0	582.0
F	173046	23.93	23.76	-0.17	31.2	31.2	0.0	581.0
	173111	24.31	24.32	+0.01	30.3	30.5	+0.2	582.0
	173112	24.51	24.65	+0.14	30.7	30.8	+0.1	582.5
G	173050	22.54	22.69	+0.15	32.3	32.3	0.0	582.5
	173051	22.69	22.83	+0.14	32.3	32.5	+0.2	582.5
	173052	21.68	21.95	+0.27	32.2	32.6	+0.4	583.0
H	173056	23.28	23.43	+0.15	29.8	29.9	+0.1	582.5
	173057	23.69	23.73	+0.04	30.0	29.9	-0.1	582.0
	173122	23.25	23.42	+0.17	29.8	29.9	+0.1	582.5
I	173058	30.86	30.95	+0.09	27.5	27.5	0.0	582.0
	173120	27.27	27.30	+0.03	27.7	27.6	-0.1	582.0
	173121	27.32	27.43	+0.11	28.0	27.9	-0.1	582.0
J	173191	24.26	24.10	-0.16	30.0	29.9	-0.1	581.0
	173192	23.64	23.62	-0.02	30.1	30.3	+0.2	582.0
	173272	25.74	25.76	+0.02	29.8	29.8	0.0	582.0
K	173124	26.83	26.82	-0.01	27.0	27.0	0.0	582.0
	173173	25.93	26.13	+0.20	26.6	26.8	+0.2	583.0
	173217	26.66	26.87	+0.21	25.3	25.5	+0.2	583.0

(Continued on the following page)

TABLE II--Continued

COMPARISON OF ESTIMATES OF PURITY AND LUMINOUS REFLECTANCE COMPUTED

FROM TWO AND FOUR REFLECTANCE MEASUREMENTS

Mill	File No.	Luminous Reflectance, %			Purity, %			Dominant Wavelength, ^a mmu
		Four Reflec- tance Method	Two Reflec- tance Method	Differ- ence	Four Reflec- tance Method	Two Reflec- tance Method	Differ- ence	
L	173061	25.14	25.33	+0.19	31.0	31.2	+0.2	582.5
	173062	23.97	24.20	+0.23	31.0	31.2	+0.2	583.0
	173063	24.84	24.84	0.0	32.2	32.2	0.0	582.0
M	173179 ^c	21.64	21.71	+0.07	29.5	29.5	0.0	582.0
	173179 ^e	21.36	21.44	+0.08	29.5	29.5	0.0	582.0
	173180	22.70	22.59	+0.11	29.8b	29.3	-0.5	581.5
N	173065 ^c	26.86	27.13	+0.27	28.0	28.4	+0.4	583.0
	173065 ^d	26.86	27.04	+0.18	28.4	28.6	+0.2	582.5
	173065 ^e	26.84	26.91	+0.07	28.0	28.2	+0.2	582.0
O	173117 ^c	27.49	27.63	+0.14	29.0	29.0	0.0	582.5
	173117 ^d	29.62	29.54	-0.08	27.5	27.5	0.0	582.0
	173117 ^e	29.90	29.96	+0.06	28.0	28.0	0.0	582.0
P	173226	22.48	22.73	+0.25	31.0	31.2	+0.2	583.0
	173227	23.72	23.84	+0.12	29.8	29.7	-0.1	582.5
	173228	23.86	24.08	+0.22	30.1	30.4	+0.3	583.0
Q	173116 ^c	21.80	21.89	+0.09	30.7	30.8	+0.1	582.5
	173116 ^d	22.14	22.32	+0.18	30.4	30.6	+0.2	582.5
	173116 ^e	22.30	22.30	0.00	30.2	30.4	+0.2	582.0
S	173169	25.86	26.12	+0.26	28.2	28.4	+0.2	583.0
	173170	26.16	26.11	-0.05	29.4	29.5	+0.1	582.0
	173186	25.98	26.06	+0.08	29.5	29.6	+0.1	582.0

^a As originally determined from reflectance data at four wavelengths.

^b This value appears to have been incorrectly read from the chromaticity charts. A value of 29.4 would appear more correct.

^c Sheet No. D-1 in Proj. 1108-13 sampling system.

^d Sheet No. D-3 in Proj. 1108-13 sampling system.

^e Sheet No. D-5 in Proj. 1108-13 sampling system.

TABLE III
DISTRIBUTION OF DIFFERENCES

Range of Differences	No. of Samples	
	Luminous Reflectance	Purity
+0.40 to +0.39		3
+0.20 to +0.29	12	5
+0.10 to +0.19	16	14
0 to +0.09	15	9
-0.01 to -0.10	5	14
-0.11 to -0.20	3	5
-0.21 to -0.30		
-0.31 to -0.40		
-0.41 to -0.50		1
Total	51	51

With respect to luminous reflectance, it may be noted that the differences between methods clustered in the range between +0.29 and -0.20--- the actual range was +0.27 to -0.17. The frequency distribution shows that the differences tended to be predominantly positive. This tendency may arise because the average dominant wavelength of the samples included herein was slightly above 582.0 mmu---actually, near 582.3 mmu. Because the two-reflectance method assumes a constant dominant wavelength, deviations from the assumed value will bring about an error in the calculated luminous reflectance. The error will be a function of the magnitude of the deviation and will be positive if the real dominant wavelength is greater than 582.0 mmu. That the differences are related to dominant wavelength is shown below.

Dominant Wavelength, mmu	No. of Samples	Average Difference
581.0	2	-0.16
581.5	2	-0.10
582.0	20	+0.03
582.5	16	+0.15
583.0	11	+0.24

Thus, for the twenty samples exhibiting a dominant wavelength of 582.0 mmu, the average difference in luminous reflectance was only 0.03. At 582.5 and 583.0 mmu, the average differences were +0.15 and +0.24, respectively. For the four samples exhibiting dominant wavelengths less than 582.0 mmu, the average differences were also in the proper order.

With respect to purity, the frequency distribution in Table III is somewhat similar to that shown for luminous reflectance. It may be remarked that the differences might be expected to be somewhat more erratic because of the graphical interpolation required in estimating purity from the trichromatic coefficients. Differences in chart reading may easily be as large as ± 0.1 or 0.2 units. In fact, the extreme difference of -0.5 shown in Tables II and III seems to have arisen from an error in reading the charts with the original data. In any event, the direction of the deviations between methods should be a function of the difference between sample dominant wavelength and the assumed value of 582.0 mmu. That such tends to be the case is shown below.

Dominant Wavelength, mmu	No. of Samples	Average Difference
581.0	2	-0.05
581.5	2	-0.25
582.0	20	+0.04
582.5	16	+0.13
583.0	11	+0.27

With the exception of the highly negative value of -0.25 at 581.5 which is probably a result of a chart reading error, the results vary in the expected manner with dominant wavelength.

In summary, the results presented herein indicate that the previous method used to define the color characteristics of unbleached kraft liner may be simplified by making use of the experimental evidence suggesting that the dominant wavelength of unbleached kraft liner is essentially a constant. Under

these circumstances reflectance measurements at two wavelengths--457 and 596 mmu--make it possible to compute the purity and luminous reflectance of 42-lb. unbleached kraft liner samples.

If this simplification were employed, the necessary computations could be simplified by either of the following procedures:

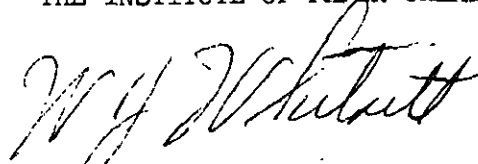
1. Prepare nomographs relating reflectance readings at 457 and 596 mmu to purity and luminous reflectance; or
2. Prepare tables for the same purpose. Because the range of reflectance values encountered at each wavelength is comparatively narrow-- perhaps 10 or 15 units--the computational time required to prepare such tables might be less than that required to prepare nomographs.

The simplified method presented above makes it possible to characterize the color of 42-lb. kraft linerboard by means of purity and luminous reflectance with little loss in precision but a marked gain in the amount of time required as compared to the two selected ordinate methods. Further, it is believed the method of computing the optical properties may be reduced to merely reading the values of these properties from a specially prepared chart.

LITERATURE CITED

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W. J. Whitsitt, Research Aide,
Container Section



R. C. McKee, Chief, Container Section